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FORM PTO-1390 (REV. 12-2001) U.S. DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE **TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371**		ATTORNEY 'S DOCKET NUMBER 722-X02-021 U.S. APPLICATION NO. (If known, see 37 CFR 1.5 10/049924
INTERNATIONAL APPLICATION NO. PCT NO. GB00/03180	INTERNATIONAL FILING DATE AUGUST 18, 2000	PRIORITY DATE CLAIMED AUGUST 20, 1999

TITLE OF INVENTION
DEMODULATOR

APPLICANT(S) FOR DO/EO/US
TIMOTHY NEWTON

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. [x] This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2. [ ] This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3. [ ] This is an express request to begin national examination procedures (35 U.S.C. 371(f)). The submission must include items (5), (6), (9) and (21) indicated below.
4. [x] The US has been elected by the expiration of 19 months from the priority date (Article 31).
5. [x] A copy of the International Application as filed (35 U.S.C. 371(c)(2))
   a. [x] is attached hereto (required only if not communicated by the International Bureau).
   b. [x] has been communicated by the International Bureau.
   c. [ ] is not required, as the application was filed in the United States Receiving Office (RO/US).
6. [ ] An English language translation of the International Application as filed (35 U.S.C. 371(c)(2)).
   a. [ ] is attached hereto.
   b. [ ] has been previously submitted under 35 U.S.C. 154(d)(4).
7. [x] Amendments to the claims of the International Aplication under PCT Article 19 (35 U.S.C. 371(c)(3))
   a. [x] are attached hereto (required only if not communicated by the International Bureau).
   b. [x] have been communicated by the International Bureau.
   c. [ ] have not been made; however, the time limit for making such amendments has NOT expired.
   d. [ ] have not been made and will not be made.
8. [ ] An English language translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371 (c)(3)).
9. [ ] An oath or declaration of the inventor(s) (35 U.S.C. 371(c)(4)).
10. [ ] An English lanugage translation of the annexes of the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371(c)(5)).

Items 11 to 20 below concern document(s) or information included:

11. [ ] An Information Disclosure Statement under 37 CFR 1.97 and 1.98.
12. [ ] An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
13. [x] A FIRST preliminary amendment.
14. [ ] A SECOND or SUBSEQUENT preliminary amendment.
15. [x] A substitute specification.
16. [ ] A change of power of attorney and/or address letter.
17. [ ] A computer-readable form of the sequence listing in accordance with PCT Rule 13ter.2 and 35 U.S.C. 1.821 - 1.825.
18. [ ] A second copy of the published international application under 35 U.S.C. 154(d)(4).
19. [ ] A second copy of the English language translation of the international application under 35 U.S.C. 154(d)(4).
20. [x] Other items or information:

COPY OF INT'L PRELIMINARY EXAMINATION REPORT; MARKED-UP SPECIFICATION; 1 SHT DWG; COPY OF PUBLISHED APPLICATION WO 01/15400 A2, CERTIFICATE OF EXPRESS MAILING; POSTCARD

10049924 .100202

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U.S. APPLICATION NO. (if known, see 37 CFR 1.5)	INTERNATIONAL APPLICATION NO.	ATTORNEY'S DOCKET NUMBER
10/049924	PCT No. GB00/03180	722-X02-021

	CALCULATIONS	PTO USE ONLY
21. [x] The following fees are submitted: **BASIC NATIONAL FEE (37 CFR 1.492 (a) (1) - (5)):** Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2)) paid to USPTO and International Search Report not prepared by the EPO or JPO .... **$1040.00** International preliminary examination fee (37 CFR 1.482) not paid to USPTO but International Search Report prepared by the EPO or JPO .... **$890.00** International preliminary examination fee (37 CFR 1.482) not paid to USPTO but international search fee (37 CFR 1.445(a)(2)) paid to USPTO .... **$740.00** International preliminary examination fee (37 CFR 1.482) paid to USPTO but all claims did not satisfy provisions of PCT Article 33(1)-(4) .... **$710.00** International preliminary examination fee (37 CFR 1.482) paid to USPTO and all claims satisfied provisions of PCT Article 33(1)-(4) **$100.00**		
ENTER APPROPRIATE BASIC FEE AMOUNT =	$ 890.00	
Surcharge of **$130.00** for furnishing the oath or declaration later than [ ] 20 [x] 30 months from the earliest claimed priority date (37 CFR 1.492(e)).	$ 130.00	

CLAIMS	NUMBER FILED	NUMBER EXTRA	RATE	$	
Total claims	5 - 20 =	0	x **$18.00**	$	
Independent claims	4 - 3 =	1	x **$84.00**	$ $84.00	
MULTIPLE DEPENDENT CLAIM(S) (if applicable)			+ **$280.00**	$	

TOTAL OF ABOVE CALCULATIONS =	$ 1104.00	
[x] Applicant claims small entity status. See 37 CFR 1.27. The fees indicated above are reduced by 1/2. +	$ 552.00	
SUBTOTAL =	$	
Processing fee of **$130.00** for furnishing the English translation later than [ ] 20 [ ] 30 months from the earliest claimed priority date (37 CFR 1.492(f)).	$	
TOTAL NATIONAL FEE =	$ 552.00	
Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31). **$40.00** per property +	$	
TOTAL FEES ENCLOSED =	$ 552.00	
	Amount to be refunded:	$
	charged:	$

a. [ ] A check in the amount of $ ________________ to cover the above fees is enclosed.

b. [x] Please charge my Deposit Account No. 500601 in the amount of $ 552.00 to cover the above fees. A duplicate copy of this sheet is enclosed.

c. [x] The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No. 500601. A duplicate copy of this sheet is enclosed.

d. [ ] Fees are to be charged to a credit card. **WARNING:** Information on this form may become public. **Credit card information should not be included on this form.** Provide credit card information and authorization on PTO-2038.

NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137 (a) or (b)) must be filed and granted to restore the application to pending status.

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REGISTRATION NUMBER

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PATENT Attorney Docket No.: 722-X02-021

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant/Inventor: Timothy Newton

Serial/Patent No.: National Stage filing of PCT No. GB00/03180 Group Art

Unit: Filed/Issued: February 20, 2002 Examiner:

For/Title: MODULATOR

CERTIFICATE OF EXPRESS MAILING

PATENTS
EXPRESS "Express Mail" Mailing Label number EV 053647560 US
Date of Deposit February 20, 2002

I hereby certify that the attached paper(s) or fee(s) is/are being deposited with the United States Postal Services "Express Mail Post Office to Addressee" service under 37 CFR §1.10 on the date indicated above and is addressed to the Commissioner of Patents & Trademark, Washington D.C. 20231.

Martin Fleit
(Signature of person mailing paper or fee)

MARTIN FLEIT
(Typed or printed name of person mailing paper or fee)

10/049924
JC10 Rec'd PCT/PTO 20 FEB 2002

PATENT Attorney Docket No.: 722-X02-021

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant/Inventor: Timothy Newton

Serial/Patent No.: National Stage filing of PCT No. GB00/03180 Group Art

Unit: Filed/Issued: February 20, 2002 Examiner:

For/Title: MODULATOR

PRELIMINARY AMENDMENT

Assistant Commissioner for Patents
Washington, D. C. 20231

Dear Sir:

With respect to the above-entitled application, kindly amend as follows:

IN THE SPECIFICATION

Please substitute the attached specification (ATTACHMENT I) for the one originally filed. The only change is to add section titles.

IN THE CLAIMS

Please amend claims 3 and 4 as follows (marked up copy of claims, see ATTACHMENT II).

- - 3. A method of demodulating a QAM signal, using the carrier detection method of claim 1 for carrier recovery.

4. A carrier signal detector for detecting the phase and frequency of a carrier signal in QAM signals according to the method of claim 1, including sampling means for sampling the digital-in-phase binary components I and Q, down converting means, phase angle measurement means, carrier phase determination means, and carrier frequency determination means. - -

IN THE ABSTRACT

Please amend the abstract as follows (marked up copy of abstract, see ATTACHMENT III).

- - ABSTRACT

An apparatus for, and method of detecting a carrier signal of a QAM signal. The method has the steps of: (a) sampling the digital-in-phase binary components I and Q of an incoming QAM modulated signal, (b) down-converting the components I and Q to a baseband frequency, (c) scaling the components I and Q so that the I and Q magnitudes are within a range of those expected for the constellation, (d) deriving the average times-n phase for the constellation, (e) determining the phase of the carrier signal, and (f) determining the frequency of the carrier signal by calculating the maximum amplitude component in the complex Fourier transform F of data from the samples. - -

REMARKS

The amendments made above are for the purpose of placing the application in conformity with the formalities required by the Rules of Practice and to enable examination on the merits.

Respectfully submitted,

Martin Fleit, Reg. #16,900

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ATTACHMENT I

SUBSTITUTE SPECIFICATION

MODULATOR

BACKGROUND OF THE INVENTION
Field of the Invention

This invention relates to the detection of carrier signals of Quadrature Amplitude Modulated (QAM) signals and Phase-Shift Keyed (PSK) signals and domodulators for demodulating QAM and PSK signals.

Prior Art

With QAM signals, two carrier signals in phase quadrature are amplitude modulated by a modulating signal and combined for transmission. Each transmitted symbol can thus have a relatively large number of phase and amplitude states, which are generally illustrated as signal points in a signal point "constellation" in a phase plane diagram. The binary components (I and Q) of the two carrier signals are plotted with the values of I along a horizontal axis and the values of Q along an orthogonal vertical axis. PSK signals are restricted set of QAM signals, with constellation points on one or more rings in the phase plane diagram.

Phase shift errors cause the constellation points to rotate through an angle φ from the position where the two carriers are in phase quadrature, and it is customary to use correction algorithms to cancel out the rotation and lock the signal.

Conventional QAM demodulators extract from the combined modulated signal, two binary components I and Q modulated in phase quadrature. The combined modulated signal is generally expressed by $I \cos(2\pi ft) + Q \sin(2\pi ft)$. An oscillator is used to generate two signals in phase quadrature at a frequency close to the anticipated carrier frequency, f, but in phase. The oscillator signals are mixed with the modulated signal to give two channels, I and Q, and an ac component of a frequency twice that of the respective carrier. The ac component is removed leaving two binary signals I and Q.

In order to demodulate the modulated QAM signal, the carrier phase and frequency needs to be accurately determined and extracted from the modulated signal.

All carrier frequency extraction algorithms exploit non-linearity of the modulated signal. Standard techniques are discussed in Webb and Hanzo, "Modem Quadrature Amplitude

Modulation" IEEE Press and Pentech Press, 1994. The main techniques for carrier recovery are:

(a) times-n carrier recovery where the signal is raised to the power of n, and the signal locked to n-times the carrier frequency; and

(b) decision directed carrier recovery - where a decision is made as to the nearest constellation point and the error used to modify the frequency.

Decision-directed feedback can only be used for small frequency errors, (much less than bandwidth/n), as the symbols may be incorrectly determined for larger errors. For the same reason the carrier may not be determined if the signal has poor equalisation.

Times-n recovery does not require the signals to be equalised as well as that for decision-directed recovery. Furthermore, times-n recovery has a much wider capture frequency. However, previously known times-n recovery techniques cannot be applied to arbitrary constellations, and do not make use of the symmetry of constellation points.

SUMMARY OF THE INVENTION

The present invention uses the time-n technique but can be applied to arbitrary constellations and makes better use of the symmetry in the constellation information than was possible with previously known times-n recovery techniques. The present invention does not require well-equalised signals and has a wide capture frequency. The technique of the present invention also provides carrier phase detection as well as frequency detection.

In one aspect of the present invention, there is provided a method of detecting a carrier signal of a QAM signal comprising the steps of: -

(a) sampling the digital-in-phase binary components I and Q of an incoming QAM modulated signal,

(b) down-converting the components I and Q to a baseband frequency,

(c) scaling the components I and Q so that the I and Q magnitudes are within a range of those expected for the constellation,

(d) deriving the average times-n phase for the constellation by calculating the complex vector Φ, where Φ is given by: -

$$\Phi(r) = \frac{\Sigma_p w(r-r_p)\exp(in\varphi_p)}{\Sigma_p w(r-r_p)}$$

where p is an index running over symbols in the constellation;

i is the $\sqrt{-1}$

r_p is the radius to the constellation point;

φ_p is the phase of the constellation point;

n is the constellation symmetry (For example 4 for four-fold symmetry, e.g., for 16QAM); and,

w is a smoothing function

(e) determining the phase of the carrier signal, and

(f) determining the frequency of the carrier signal by calculating the maximum amplitude component in the complex Fourier transform F of data from the samples according to the following equation :-

$$F(\omega) = \sum_d W_d \Phi^*(r_d)\exp(in\phi_d - i\omega d)$$

where d is an index running over data samples;

r_d is the amplitude of a data sample;

φ_d is the phase of a data sample;

W_d is a (real positive) windowing function (e.g. Hanning);

ω is angular frequency = $2\Pi f$, where f is the real frequency.

In a further aspect of the present invention, there is provided a method of demodulating a QAM signal comprising the steps of :-

(a) sampling the digital-in-phase binary components I and Q of an incoming QAM modulated signal,

(b) down-converting the components I and Q to a baseband frequency,

(c) scaling the components I and Q so that the I and Q magnitudes are those expected for the constellation,

(d) deriving the average times-n phase for the constellation by calculating the complex vector Φ where Φ is given by:

$$\Phi(r) = \frac{\Sigma_p w(r-r_p)\exp(in\varphi_p)}{\Sigma_p w(r-r_p)}$$

where p is an index running over symbols in the constellation;
r_p is the radius to the constellation point;
φ_p is the phase of the constellation point;
n is the constellation symmetry (for example, 4 for four-fold symmetry, e.g., for 16QAM);
w is a smoothing function

(e) determining the phase of the carrier signal, and

(f) determining the frequency of the carrier signal by calculating the maximum amplitude component in the complex Fourier transform F of data from the samples according to the following equation :-

$$F(\omega)=\sum_d W_d \Phi^*(r_d)\exp(in\phi_d - i\omega d)$$

where d is an index running over data samples;

r_d is the amplitude of a data sample;

φ_d is the phase of a data sample;

W_d is a (real positive) windowing function (e.g. Hanning);

ω is angular frequency = 2Πf, where f is the real frequency;

and,

(g) subtracting the detected carrier signal from the incoming QAM signal to derive the modulating signal in the incoming QAM signal.

In another aspect of the present invention there is provided a carrier signal detector for detecting the phase and frequency of a carrier signal in Quadrature Amplitude Modulated signals, said detector comprising :-

(a) sampling means for sampling the digital-in-phase components I and Q of an incoming QAM modulated signal,

(b) frequency conversion means for down-converting the components I and Q to a baseband frequency,

(c) phase angle measurement means for deriving the average times-n phase operable to calculate the complex vector Φ where Φ is given by:-

$$\Phi(r)=\frac{\sum_p \iint |w(r\cos\phi - I_p, r\sin\phi - Q_p)| \exp(in\phi) r\,d\phi}{\sum_p \iint |w(r\cos\phi - I_p, r\sin\phi - Q_p)| r\,d\phi}$$

where p is an index running over symbols in the constellation;

i is the $\sqrt{-1}$

r_p is the radius to the constellation point;

φ is the phase of the constellation point;

n is the constellation symmetry (for example, 4 for four-fold symmetry, e.g., for 16QAM);

w is a smoothing function;

(d) carrier phase determination means for determining the phase of the carrier signal in the incoming QAM signal, and

(e) frequency determining means for determining the frequency of the carrier signal in the incoming QAM signal by calculating the maximum amplitude component in the complex Fourier transform F of data from the samples according to the following equation:

$$F(\omega)=\sum_{d} W_d \Phi^*(r_d)\exp(in\phi_d - i\omega d)$$

where

d is an index running over data samples;

r_d is the amplitude of a data sample;

ϕ_d is the phase a data sample;

W_d is a (real positive) windowing function (e.g. Hanning);

ω is angular frequency = $2\Pi f$ where f is the real frequency.

In another aspect of the present invention there is provided a demodulator for demodulating Quadrature Amplitude Modulated signals, said demodulator comprising :-

(a) sampling means for sampling the digital-in-phase components I and Q of an incoming QAM modulated signal,

(b) frequency conversion means for down-converting the components I and Q to a baseband frequency,

(c) phase angle measurement means for deriving the average times-n phase operable to calculate the complex vector φ where φ is given by :-

$$\Phi(r) = \frac{\sum_p \iint \left| w(r\cos\phi - I_p, r\sin\phi - Q_p) \right| \exp(in\phi) r d\phi}{\sum_p \iint \left| w(r\cos\phi - I_p, r\sin\phi - Q_p) \right| r d\phi}$$

where p is an index running over symbols in the constellation;

r is the radius to the constellation point;

φ is the phase of the constellation point;

n is the constellation symmetry (for example, 4 for four-fold symmetry, e.g., for I6QAM);

w is a smoothing function;

(d) carrier phase determination means for determining the phase of the carrier signal;

(e) frequency determining means for determining the frequency of the carrier signal by calculating the maximum amplitude component in the complex Fourier transform F of data from the samples according to the following equation:

$$F(\omega) = \sum_d W_d \Phi^*(r_d) \exp(in\phi_d - i\omega d)$$

where d is an index running over data samples;

rd is the amplitude of a data sample;

φ_d is the phase of a data sample;

W_d is a (real positive) windowing function (e.g. Hanning);

ω is angular frequency = 2Πf, where f is the real frequency; and

(f) carrier subtraction means for subtracting the detected carrier signal from the incoming QAM signal.

Where there are many constellation points with widely differing phases, the magnitude of (I) is small, otherwise the magnitude is large, and hence those constellation points that provide little information on the carrier frequency will be weighted down.

The phase of (I) is the average times-n phase of the points with that radius. When this is subtracted from the phase of the sample data, this improves the recovery algorithm by removing phase errors for samples with different amplitudes.

Preferably the weighting function (w) is chosen to have a spread comparable to that expected in the data, and zero beyond that. The weighting function may be Gaussian, triangular, or rectangular or other.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will now be described, by way of an example, with reference to the accompanying drawings, in which:

Figure 1 is a schematic representation of a demodulator constructed in accordance with the present invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Referring to Figure 1 the demodulator (10) comprises basically two main components, namely a high performance programmable digital signal processor (11) built around a number of fairly conventional hardware signal processing integrated circuits, and a high power computer 12 comprising two power PC's 13, 14. One of the PC's (13) serves as the controller and the other handles the input and output interfaces.

These two components 11, 12, are coupled, and large RAM buffers are provided to collect snapshots of data which are read by the PC's 13, 14. The PC's 13, 14 are able to upload the required processing parameters to the digital signal-processor 11, and also

provide a remote connection facility *15*, either via a Wide Area Network (WAN) or serial port.

There is a variety of conventional options available for this interface.

Remote access allows full interactive control of the demodulator 10, including retrieval of snapshot data, uploading digital signal processing data, and uploading of the PC's software.
The digital signal processor (11) provides a generic capability for equalisation filtering and demodulation. Within the underlying constraints of the hardware, such as filter lengths and sampling rates, any signal format can be handled. Standard modulation schemes such as 16, 32, 64, 128, 256, 512,1024 QAM and BPSK, QPSK, S-QPSK, 8-PSK can be handled by the demodulator.

The equalisation method used is a 64 complex tap FIR filter operating on samples at twice the symbol rate.

Mounting of collection operations can be very time consuming. However the present demodulator can be used against unknown signal types and can be programmed in the field to cope with almost any signal type.

The demodulator is provided with a screen 16 on which the constellation points of a phase-plane map can be displayed.

In use of the demodulator 10, the incoming modulated QAM signal (at an intermediate frequency, typically of 140MHz, with an input impedance of 50 ohms), is supplied at the input 17 to an analogue front-end unit 18. The front-end unit 18 converts the 140MHz analogue signal to an analogue signal centred approximately at 40MHz. The 40MHz

analogue signal is digitised at a sample rate of 160MHz, and then mixed down to baseband with I and Q channels sampled at 80MHz.

Data are captured from the digitised signal at this point, to identify the approximate symbol rate. The signal is then resampled at twice the symbol clock rate. Data are captured after resampling, and the symbol clock rate is then accurately identified and tracked.

The digitised signal is equalised and decimated by a factor of two to give digital I and Q signals at the symbol rate. These I and Q data are captured and form the input to the carrier recovery which is performed according to the present invention. The detected carrier frequency and phase are used to control a digital mixer, the output of which is passed to a look-up table that translates the I and Q values to the final symbol values. The detected carrier signal is subsequently subtracted from the incoming modulated signal in order to derive the modulating signal of the incoming signal.

ATTACHMENT II

MARKED UP COPY OF AMENDED CLAIMS

3. (Amended) A method of demodulating a QAM signal, [including] using the carrier detection[.] method of claim 1 [or claim 2] for carrier recovery.

4. (Amended) A carrier signal detector for detecting the phase and frequency of a carrier signal in QAM signals according to the method of claim 1 [or claim 2], including [or consisting of] sampling means for sampling the digital-in-phase binary components I and Q, down converting means, phase angle measurement means, carrier phase determination means, and carrier frequency determination means.

ATTACHMENT III

Marked up

ABSTRACT.

An apparatus for, and method of detecting a carrier signal of a QAM signal. The method [comprises] has the steps of: (a) sampling the digital-in-phase binary components I and Q of an incoming QAM modulated signal, (b) down-converting the components I and Q to a baseband frequency, (c) scaling the components I and Q so that the I and Q magnitudes are within a range of those expected for the constellation, (d) deriving the average times-n phase for the constellation, (e) determining the phase of the carrier signal, and (f) determining the frequency of the carrier signal by calculating the maximum amplitude component in the complex Fourier transform F of data from the samples. [The average times-n phase is derived by calculating the complex vector Φ where Φ is given by formula (1) where is an index running over symbols in the constellation: is the v-I; r_p is the radius to the constellation point; Φ_d is the phase of the constellation point; is the constellation symmetry (For example 4 for four-fold symmetry, e.g., for 16QAM); and is a smoothing function. The frequency of the carrier signal is calculated according to the following equation F(ω) = $\sum_d W_d \varphi * (r_d) \exp(in\phi_d - i\omega d)$ is the amplitude of a data sample; Φ is the phase of a data sample; W_d is a (real positive) windowing function (e.g. Hanning); ω is angular frequency = 2πf, where f is the real frequency.]

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1/PRTS

This invention relates to the detection of carrier signals of Quadrature Amplitude Modulated (QAM) signals and Phase-Shift Keyed (PSK) signals and domodulators for demodulating QAM and PSK signals.

With QAM signals, two carrier signals in phase quadrature are amplitude modulated by a modulating signal and combined for transmission. Each transmitted symbol can thus have a relatively large number of phase and amplitude states, which are generally illustrated as signal points in a signal point "constellation" in a phase plane diagram. The binary components (I and Q) of the two carrier signals are plotted with the values of I along a horizontal axis and the values of Q along an orthogonal vertical axis. PSK signals are restricted set of QAM signals, with constellation points on one or more rings in the phase plane diagram.

Phase shift errors cause the constellation points to rotate through an angle φ from the position where the two carriers are in phase quadrature, and it is customary to use correction algorithms to cancel out the rotation and lock the signal.

Conventional QAM demodulators extract from the combined modulated signal, two binary components I and Q modulated in phase quadrature. The combined modulated signal is generally expressed by $I \cos(2\pi ft) + Q \sin(2\pi ft)$. An oscillator is used to generate two signals in phase quadrature at a frequency close to the anticipated carrier frequency, f, but in phase. The oscillator signals are mixed with the modulated signal to give two channels, I and Q, and an ac component of a frequency twice that of the respective carrier. The ac component is removed leaving two binary signals I and Q.

In order to demodulate the modulated QAM signal, the carrier phase and frequency needs to be accurately determined and extracted from the modulated signal.

All carrier frequency extraction algorithms exploit non-linearity of the modulated signal. Standard techniques are discussed in Webb and Hanzo, "Modern Quadrature Amplitude

Modulation" IEEE Press and Pentech Press, 1994. The main techniques for carrier recovery are:

(a) times-n carrier recovery where the signal is raised to the power of n, and the signal locked to n-times the carrier frequency; and

(b) decision directed carrier recovery - where a decision is made as to the nearest constellation point and the error used to modify the frequency.

Decision-directed feedback can only be used for small frequency errors, (much less than bandwidth/n), as the symbols may be incorrectly determined for larger errors. For the same reason the carrier may not be determined if the signal has poor equalisation.

Times-n recovery does not require the signals to be equalised as well as that for decision-directed recovery. Furthermore, times-n recovery has a much wider capture frequency. However, previously known times-n recovery techniques cannot be applied to arbitrary constellations, and do not make use of the symmetry of constellation points.

The present invention uses the time-n technique but can be applied to arbitrary constellations and makes better use of the symmetry in the constellation information than was possible with previously known times-n recovery techniques. The present invention does not require well-equalised signals and has a wide capture frequency. The technique of the present invention also provides carrier phase detection as well as frequency detection.

In one aspect of the present invention, there is provided a method of detecting a carrier signal of a QAM signal comprising the steps of: -

(a) sampling the digital-in-phase binary components I and Q of an incoming QAM modulated signal,

(b) down-converting the components I and Q to a baseband frequency,

(c) scaling the components I and Q so that the I and Q magnitudes are within a range of those expected for the constellation,

(d) deriving the average times-n phase for the constellation by calculating the complex vector Φ, where Φ is given by: -

$$\Phi(r) = \frac{\Sigma_p w(r-r_p)\exp(in\varphi_p)}{\Sigma_p w(r-r_p)}$$

where p is an index running over symbols in the constellation;

i is the $\sqrt{-1}$

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n is the constellation symmetry (For example 4 for four-fold symmetry, e.g., for 16QAM); and,

w is a smoothing function

(e) determining the phase of the carrier signal, and

(f) determining the frequency of the carrier signal by calculating the maximum amplitude component in the complex Fourier transform F of data from the samples according to the following equation :-

$$F(\omega) = \sum_d W_d \Phi^*(r_d)\exp(in\phi_d - i\omega d)$$

where d is an index running over data samples;

r_d is the amplitude of a data sample;

φ_d is the phase of a data sample;

W_d is a (real positive) windowing function (e.g. Hanning);

ω is angular frequency = $2\Pi f$, where f is the real frequency.

In a further aspect of the present invention, there is provided a method of demodulating a QAM signal comprising the steps of :-

(a) sampling the digital-in-phase binary components I and Q of an incoming QAM modulated signal,

(b) down-converting the components I and Q to a baseband frequency,

(c) scaling the components I and Q so that the I and Q magnitudes are those expected for the constellation,

(d) deriving the average times-n phase for the constellation by calculating the complex vector Φ where Φ is given by:

$$\Phi(r) = \frac{\Sigma_p w(r-r_p)\exp(in\varphi_p)}{\Sigma_p w(r-r_p)}$$

where p is an index running over symbols in the constellation;

r_p is the radius to the constellation point;

φ_p is the phase of the constellation point;

n is the constellation symmetry (for example, 4 for four-fold symmetry, e.g., for 16QAM);

w is a smoothing function

(e) determining the phase of the carrier signal, and

(f) determining the frequency of the carrier signal by calculating the maximum amplitude component in the complex Fourier transform F of data from the samples according to the following equation :-

$$F(\omega) = \sum_d W_d \Phi^*(r_d) \exp(in\phi_d - i\omega d)$$

where d is an index running over data samples;

r_d is the amplitude of a data sample;

φ_d is the phase of a data sample;

W_d is a (real positive) windowing function (e.g. Hanning);

ω is angular frequency = $2\Pi f$, where f is the real frequency;

and,

(g) subtracting the detected carrier signal from the incoming QAM signal to derive the modulating signal in the incoming QAM signal.

In another aspect of the present invention there is provided a carrier signal detector for detecting the phase and frequency of a carrier signal in Quadrature Amplitude Modulated signals, said detector comprising :-

(a) sampling means for sampling the digital-in-phase components I and Q of an incoming QAM modulated signal,

(b) frequency conversion means for down-converting the components I and Q to a baseband frequency,

(c) phase angle measurement means for deriving the average times-n phase operable to calculate the complex vector Φ where Φ is given by:-

$$\Phi(r) = \frac{\sum_p \iint |w(r\cos\phi - I_p, r\sin\phi - Q_p)| \exp(in\phi) r d\phi}{\sum_p \iint |w(r\cos\phi - I_p, r\sin\phi - Q_p)| r d\phi}$$

where p is an index running over symbols in the constellation;

i is the $\sqrt{-1}$

r_p is the radius to the constellation point;

φ is the phase of the constellation point;

n	is the constellation symmetry (for example, 4 for four-fold symmetry, e.g., for 16QAM);
w	is a smoothing function;

(d) carrier phase determination means for determining the phase of the carrier signal in the incoming QAM signal, and

(e) frequency determining means for determining the frequency of the carrier signal in the incoming QAM signal by calculating the maximum amplitude component in the complex Fourier transform F of data from the samples according to the following equation:

$$F(\omega) = \sum_{d} W_d \Phi^*(r_d) \exp(in\phi_d - i\omega d)$$

where	d	is an index running over data samples;
	r_d	is the amplitude of a data sample;
	ϕ_d	is the phase a data sample;
	W_d	is a (real positive) windowing function (e.g. Hanning);
	ω	is angular frequency = $2\Pi f$ where f is the real frequency.

In another aspect of the present invention there is provided a demodulator for demodulating Quadrature Amplitude Modulated signals, said demodulator comprising :-

(a) sampling means for sampling the digital-in-phase components I and Q of an incoming QAM modulated signal,

(b) frequency conversion means for down-converting the components I and Q to a baseband frequency,

(c) phase angle measurement means for deriving the average times-n phase operable to calculate the complex vector φ where φ is given by :-

$$\Phi(r)=\frac{\sum_{p}\iint\left|w(r\cos\phi-I_{p},r\sin\phi-Q_{p})\right|\exp(in\phi)rd\phi}{\sum_{p}\iint\left|w(r\cos\phi-I_{p},r\sin\phi-Q_{p})\right|rd\phi}$$

where p is an index running over symbols in the constellation;

r is the radius to the constellation point;

φ is the phase of the constellation point;

n is the constellation symmetry (for example, 4 for four-fold symmetry, e.g., for I6QAM);

w is a smoothing function;

(d) carrier phase determination means for determining the phase of the carrier signal;

(e) frequency determining means for determining the frequency of the carrier signal by calculating the maximum amplitude component in the complex Fourier transform F of data from the samples according to the following equation:

$$F(\omega)=\sum_{d}W_{d}\Phi^{*}(r_{d})\exp(in\phi_{d}-i\omega d)$$

where d is an index running over data samples;

rd is the amplitude of a data sample;

φ_d is the phase of a data sample;

W_d is a (real positive) windowing function (e.g. Hanning);

ω is angular frequency = 2Πf, where f is the real frequency; and

(f) carrier subtraction means for subtracting the detected carrier signal from the incoming QAM signal.

Where there are many constellation points with widely differing phases, the magnitude of (I) is small, otherwise the magnitude is large, and hence those constellation points that provide little information on the carrier frequency will be weighted down.

The phase of (I) is the average times-n phase of the points with that radius. When this is subtracted from the phase of the sample data, this improves the recovery algorithm by removing phase errors for samples with different amplitudes.

Preferably the weighting function (w) is chosen to have a spread comparable to that expected in the data, and zero beyond that. The weighting function may be Gaussian, triangular, or rectangular or other.

The present invention will now be described, by way of an example, with reference to the accompanying drawings, in which:

Figure 1 is a schematic representation of a demodulator constructed in accordance with the present invention.

Referring to Figure 1 the demodulator (10) comprises basically two main components, namely a high performance programmable digital signal processor (11) built around a number of fairly conventional hardware signal processing integrated circuits, and a high power computer 12 comprising two power PC's 13, 14. One of the PC's (13) serves as the controller and the other handles the input and output interfaces.

These two components 11, 12, are coupled, and large RAM buffers are provided to collect snapshots of data which are read by the PC's 13, 14. The PC's 13, 14 are able to upload the required processing parameters to the digital signal-processor 11, and also

provide a remote connection facility *15*, either via a Wide Area Network (WAN) or serial port.

There is a variety of conventional options available for this interface.

Remote access allows full interactive control of the demodulator 10, including retrieval of snapshot data, uploading digital signal processing data, and uploading of the PC's software.

The digital signal processor (11) provides a generic capability for equalisation filtering and demodulation. Within the underlying constraints of the hardware, such as filter lengths and sampling rates, any signal format can be handled. Standard modulation schemes such as 16, 32, 64, 128, 256, 512,1024 QAM and BPSK, QPSK, S-QPSK, 8-PSK can be handled by the demodulator.

The equalisation method used is a 64 complex tap FIR filter operating on samples at twice the symbol rate.

Mounting of collection operations can be very time consuming. However the present demodulator can be used against unknown signal types and can be programmed in the field to cope with almost any signal type.

The demodulator is provided with a screen 16 on which the constellation points of a phase-plane map can be displayed.

In use of the demodulator 10, the incoming modulated QAM signal (at an intermediate frequency, typically of 140MHz, with an input impedance of 50 ohms), is supplied at the input 17 to an analogue front-end unit 18. The front-end unit 18 converts the 140MHz analogue signal to an analogue signal centred approximately at 40MHz. The 40MHz

analogue signal is digitised at a sample rate of 160MHz, and then mixed down to baseband with I and Q channels sampled at 80MHz.

Data are captured from the digitised signal at this point, to identify the approximate symbol rate. The signal is then resampled at twice the symbol clock rate. Data are captured after resampling, and the symbol clock rate is then accurately identified and tracked.

The digitised signal is equalised and decimated by a factor of two to give digital I and Q signals at the symbol rate. These I and Q data are captured and form the input to the carrier recovery which is performed according to the present invention. The detected carrier frequency and phase are used to control a digital mixer, the output of which is passed to a look-up table that translates the I and Q values to the final symbol values. The detected carrier signal is subsequently subtracted from the incoming modulated signal in order to derive the modulating signal of the incoming signal.

CLAIMS

1. A method of detecting the carrier signal from a QAM signal, comprising the steps of: -

(a) sampling the digital-in-phase binary components I and Q of an incoming QAM modulated signal,

(b) down-converting the components I and Q to a baseband frequency,

(c) scaling the components I and Q so that the I and Q magnitudes are those expected for the constellation,

(d) deriving the average times-n phase by calculating the complex vector Φ where Φ is given by: -

$$\Phi(r) = \frac{\sum_p w(r-r_p)\exp(in\varphi_d)}{\sum_p w(r-r_p)}$$

where
p is an index running over symbols in the constellation;
i is the square root of minus 1
r_p is the radius to the constellation point;
φ_p is the phase of the constellation point;
n is the constellation symmetry (4 for four-fold symmetry, e.g., for 16QAM); and
w is a weighting function

(e) determining the frequency and phase of the carrier signal by calculating the maximum amplitude component in the complex Fourier transform F of data from the samples according to the following equation :-

$$F(\omega) = \sum_d W_d \Phi^* (r_d)\exp(in\varphi_p - i\,\omega\, d)$$

where
d is an index running over data samples;
r_d is the amplitude of a data sample;
φ_p is the phase of a data sample;
W_d is a (real positive) windowing function (e.g. Hanning);
ω is the normalised angular frequency $= 2\pi f$, where f is the real frequency

2. A method of detecting the carrier signal from a QAM signal according to claim 1, in which the equation in step (d) is replaced by:-

$$\Phi(r) = \frac{\sum_p \int | w(r\cos\phi - I_p, r\sin\phi - Q_p) | \exp(in\phi) r d\phi}{\sum_p \int | w(r\cos\phi - I_p, r\sin\phi - Q_p) | r d\phi}$$

where
- p is an index running over symbols in the constellation;
- i is the square root of minus 1;
- I_p is the I component of the pth constellation point;
- Q_p is the Q component of the pth constellation point;
- ϕ is a phase integration variable;
- n is the constellation symmetry (4 for four-fold symmetry, e.g., for 16QAM); and
- w is a weighting function.

3. A method of demodulating a QAM signal, including using the carrier detection. method of claim 1 or claim 2 for carrier recovery.

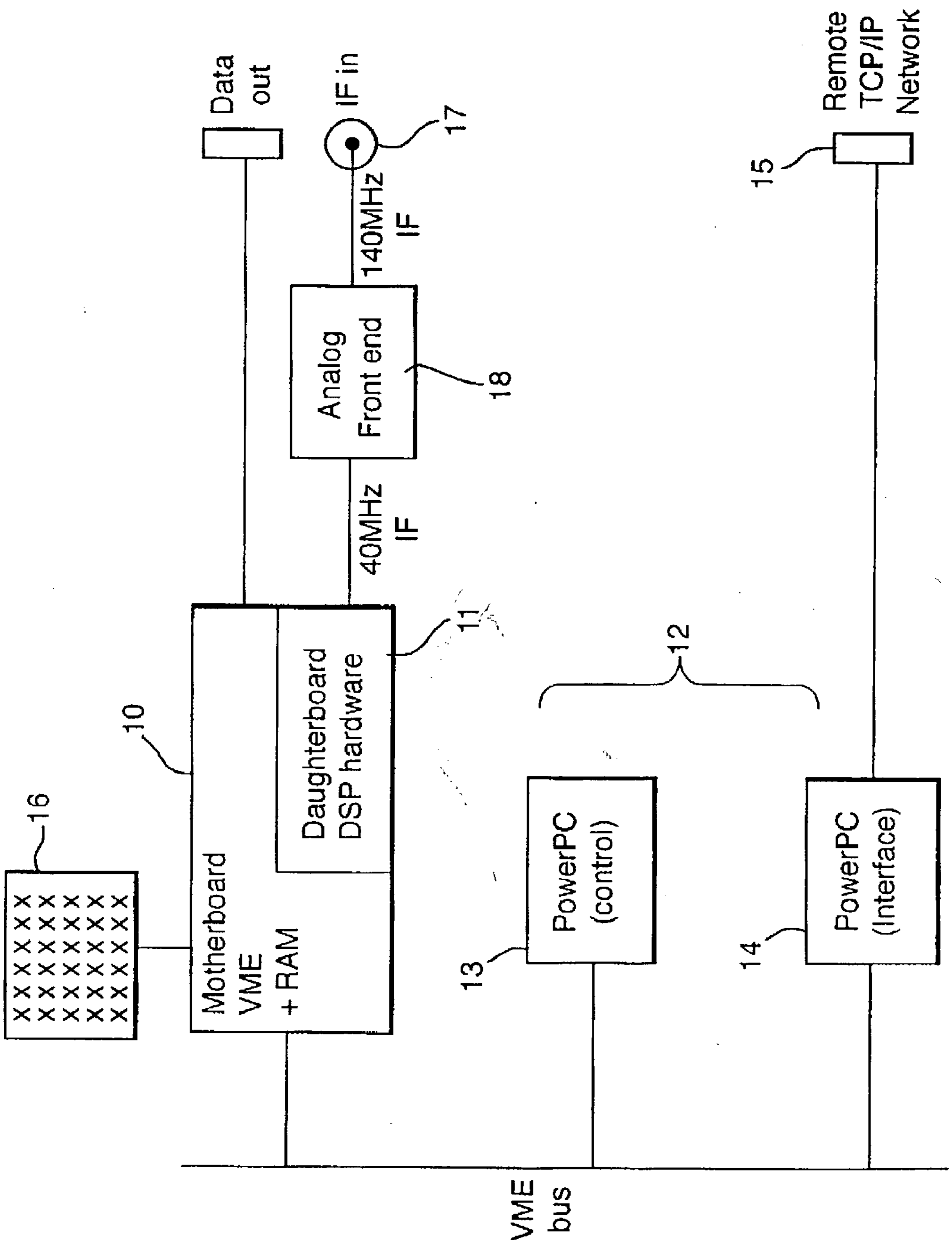
4. A carrier signal detector for detecting the phase and frequency of a carrier signal in QAM signals according to the method of claim 1 or claim 2, including or consisting of sampling means for sampling the digital-in-phase binary components I and Q, down converting means, phase angle measurement means, carrier phase determination means, and carrier frequency determination means.

5. A demodulator for QAM signals according to the method of claim 3, including the carrier signal detector according to claim 4, and QAM signal demodulating means including carrier subtraction means.

Abstract.

An apparatus for, and method of detecting a carrier signal of a QAM signal. The method comprises the steps of: (a) sampling the digital-in-phase binary components I and Q of an incoming QAM modulated signal, (b) down-converting the components I and Q to a baseband frequency, (c) scaling the components I and Q so that the I and Q magnitudes are within a range of those expected for the constellation, (d) deriving the average times-n phase for the constellation, (e) determining the phase of the carrier signal, and (f) determining the frequency of the carrier signal by calculating the maximum amplitude component in the complex Fourier transform F of data from the samples. The average times-n phase is derived by calculating the complex vector Φ where Φ is given by formula (1) where is an index running over symbols in the constellation: is the v-l; r_p is the radius to the constellation point; Φ_d is the phase of the constellation point; is the constellation symmetry (For example 4 for four-fold symmetry, e.g., for 16QAM); and is a smoothing function. The frequency of the carrier signal is calculated according to the following equation F(ω) = $\sum_d W_d \varphi * (r_d) \exp(in\phi_d - i\omega d)$ is the amplitude of a data sample; Φ is the phase of a data sample; W_d is a (real positive) windowing function (e.g. Hanning); ω is angular frequency = 2πf, where f is the real frequency.

10/049924


Data out
IF in
17
140MHz IF
Analog Front end
18
40MHz IF
11
Daughterboard DSP hardware
10
Motherboard VME + RAM
16
12
PowerPC (control)
13
PowerPC (Interface)
14
15
Remote TCP/IP Network
VME bus

DECLARATION AND POWER OF ATTORNEY FOR PATENT APPLICATION

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name;

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter that is claimed and for which a patent is sought on the invention entitled

DEMODULATOR

the specification of which:

__X__ was filed
under Attorney's Docket Number 722-X02-021
as Application No. 10/049,924 with the USPTO on February 20, 2002
as National Stage of International Application PCT/GB00/03180 filed 08/18/2000

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information material to the patentability of this application in accordance with 37 CFR 1.56.

I hereby claim the benefit of foreign priority under 35 USC 119(a)-(d) or 365(b) of any foreign application(s) for patent or inventor's certificate, or 365(a) of any PCT international application which designated at least one country other than the United States of America, listed below and have also identified below any foreign application for patent or inventor's certificate or of any PCT international application having a filing date before that of the application the priority of which is claimed:

Prior Foreign Application(s):

Number	Country	Filing Date	Priority Claimed Yes	No
9922002.2	Great Britain	Aug. 20, 1999	XXX	

I hereby claim the benefit of United States priority under 35 USC 120 of any United States application(s) or 365(c) of any PCT international applications designating the United States of America, listed below and, insofar as the subject matter of each of the claims of this application is disclosed in a listed one of the prior United States or PCT international application in the manner provided by the first paragraph of 35 USC 112, I acknowledge the duty to disclose information material to the patentability of this application as defined in 37 CFR 1.56 which became available between the filing date of the prior application and the national or PCT international filing date of this application:

U.S. Parent Application or PCT Parent Number	(Filing Date)	Parent Patent Number
PCT/GB00/03180	18 Aug. 2000	

POWER OF ATTORNEY: As a named inventor, I hereby appoint the following attorney(s) and/or agent(s) to prosecute this application and transact all business in the Patent and Trademark Office connected therewith.

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I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under 18 USC 1001 and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

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